

WP9:Light Collection R&D at Milano Bicocca

Luca Meazza for the working group

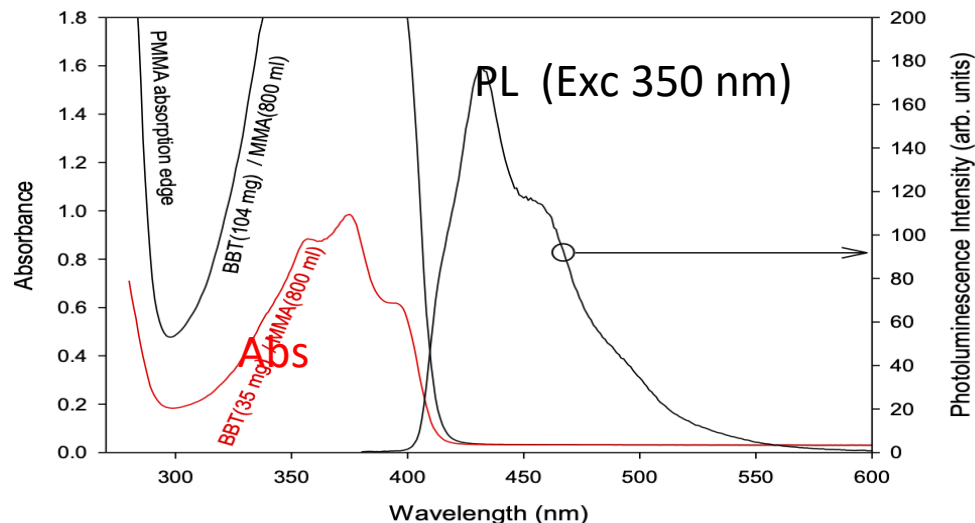


UniMiB & INFN Milano Bicocca
2° AIDAINNOVA Annual Meeting 26/04/2023



- **WLS**
 - Mass production
 - Laser cut with edge shapes
 - Measurement of the Attenuation length on thick plates.
 - Assessment of the radiopurity budget
- **Dichroics (DF)**
 - Mass production of large area 150 x 150 mm² DF
 - Assessment of the
 - dichroic thin film multilayer uniformity
 - DF Characteristics in H₂O
- Assessment of the **Photon Detection Efficiency** of the DUNE PDS system fundamental unit (X-Arapuca) **embedding WLS and DF**

- Requirements:
 - Cryoresilience
 - PMMA based (no scintillator, only Cerenkov emission)
 - Low tolerances $O(0.1 \text{ mm})$
 - Absorbption: 330-390 nm (tailored for pTP emission)
 - Emission: 420-500 nm to match the SiPM Q.E.
 - Optical Path $O(1 \text{ m})$



Absorption and Emission can be tailored on different wavelengths

The reactor to prepare the MMA syrup



The joint R&D work triggered our industrial partner* to develop in house a casting facility

The syrup preparation (MMA + initiator + chromophore) is the preliminary step to the casting of plates.

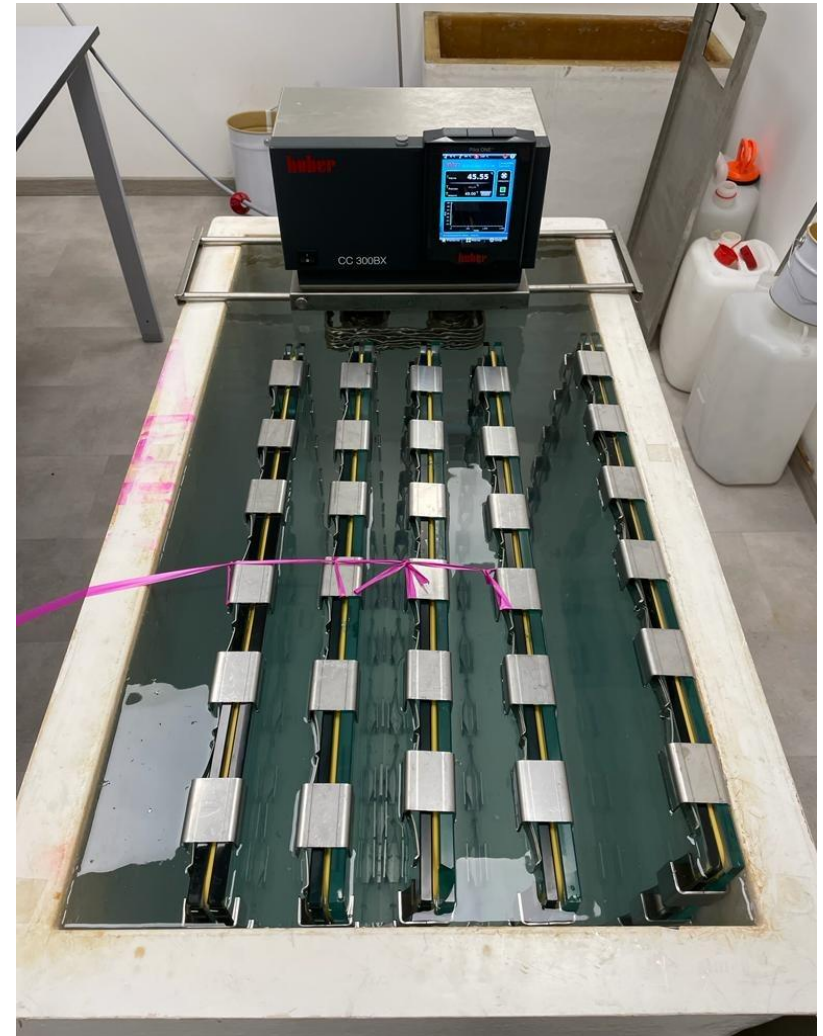
The stirrer enclosed in a cabinet can operate in protected atmosphere. It allows to reach low Rn contaminations in the WLS

* Glass to Power Co.: Former start up of Uni MiB, now quoted at Eurostock: <https://www.glasstopower.com/>

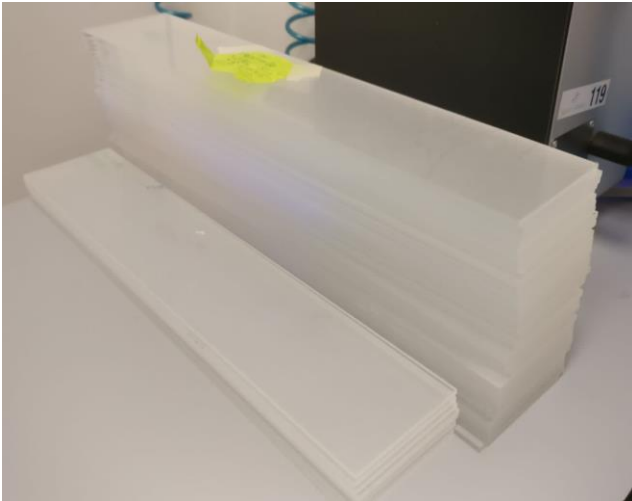
The joint R&D work triggered our industrial partner* to develop in house a casting reactor with casting capability of 5 large plates at time.

This reactor can be easily duplicated. The syrup preparation (MMA + initiator + chromophore) is the preliminary step of the plates casting

The casting reactor:
5 plates at once



* Glass to Power Co.: Former start up of Uni MiB, now quoted at Eurostock: <https://www.glasstopower.com/>



- 90 x WLS slabs for pDUNE FD1-PDS: $480 \times 93 \text{ mm}^2$ x 4mm thick

Laser cut (external industrial partner) and edge polishing procedures to cut out the casted plates in tiles defined and validated.

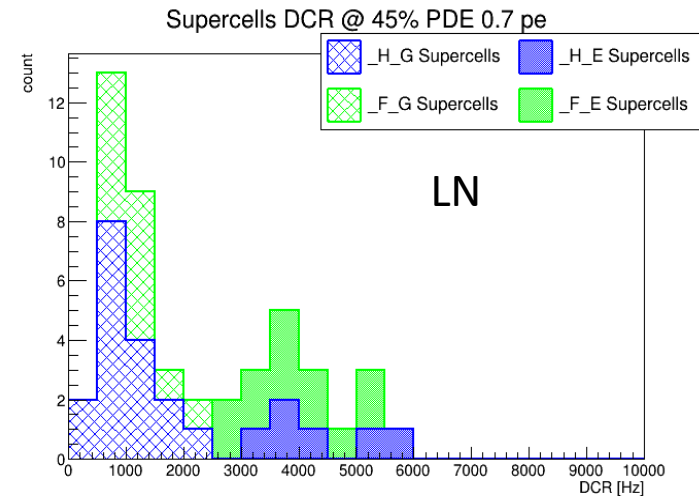
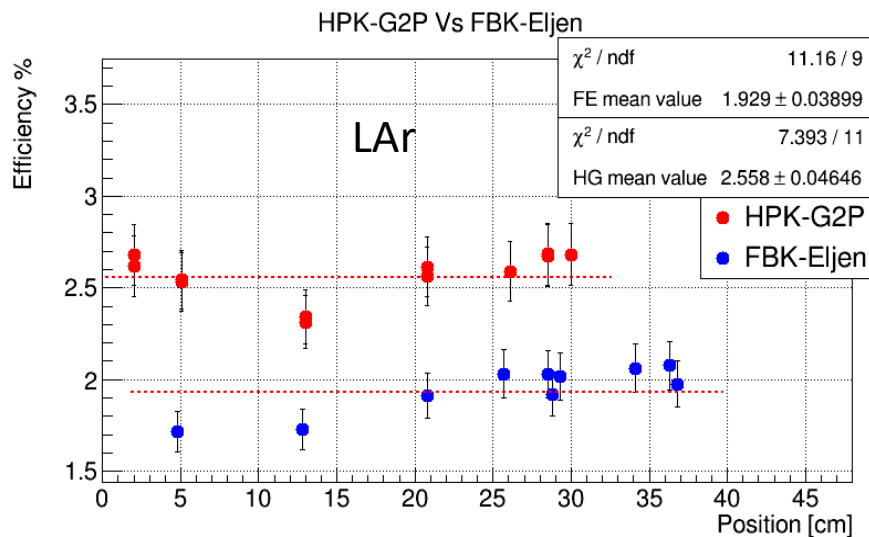


- **20** x WLS slabs for the pDUNE FD2-PDS: $607 \times 607 \text{ mm}^2$ x 4mm thick casted in one week



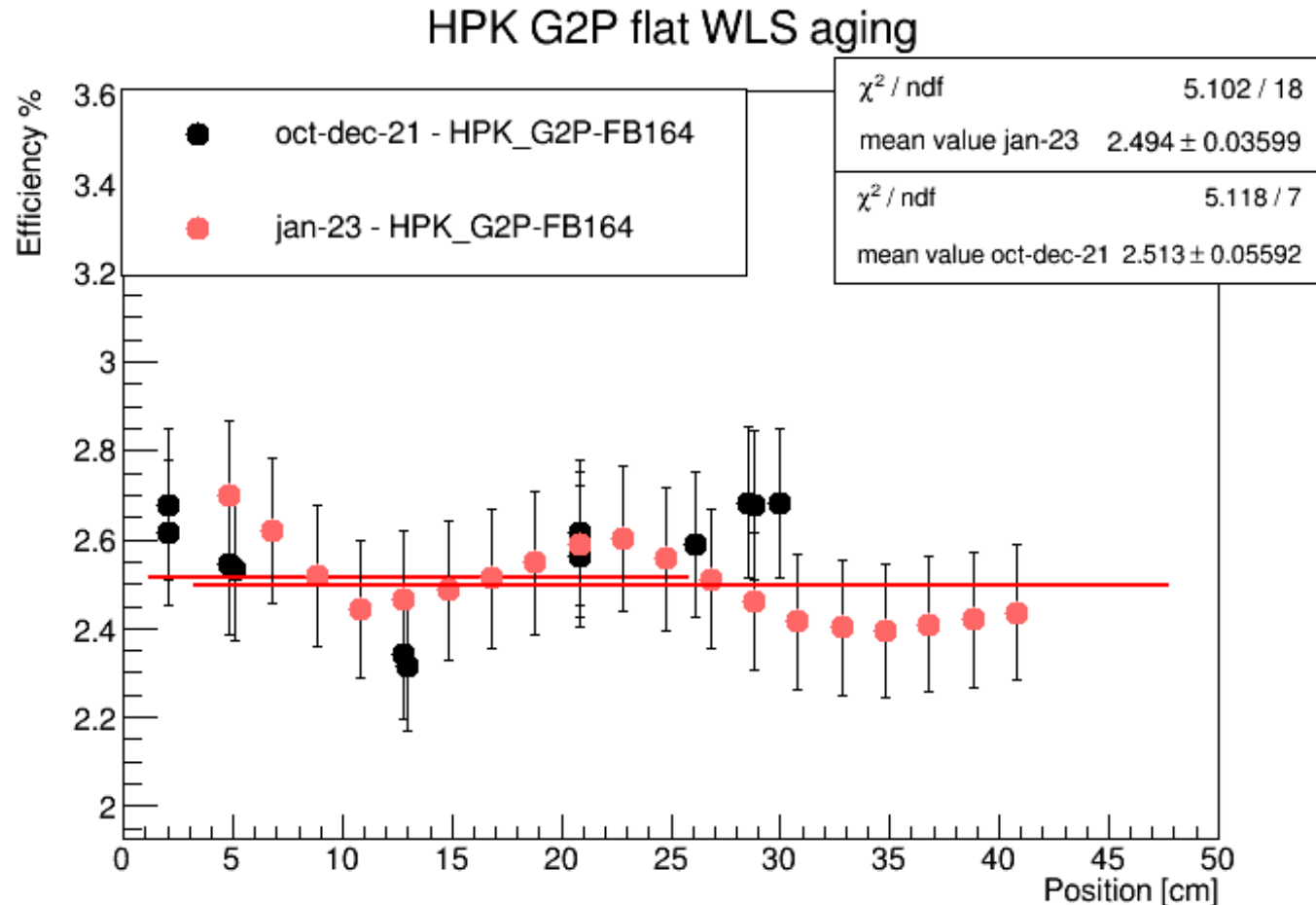
One 607 x 607 x 4 mm³ slab is being assembled in one DUNE FD2 XA cell, together with SiPMs populated on flex circuits substrate.

- **Superior Cryoresilience:** No cracks or failures in cooling/warming cycle at rate of 3-4 mm/sec of the **80 x FD1 pDUNE & 16 x FD2 Module-0 plates**
- **Stress tests:** One prototype plate underwent 15-20 thermal cycles: no failures.
- **Superior light guiding surfaces as casted**
- **Superior LY and DCR of XA cells equipped with our PMMA based WLS**



Aging assessment of WLS slabs

- ~15 thermal cycles in between oct-dec21 and jan-23.
- Tested different configurations of a 480 x 93 x 4 mm³ plate



Results from ICPMS

- U-238 and Th-232 concentration are ≤ 15 ppT (ICPMS)

Results γ -ray spectrometry (800 g plate measured over 19 days)

- plate casted and exposed to air over several months:

Preliminary measurements (limited sensitivity related to the exposed mass)

- Ra-226 < 160 $\mu\text{Bq/kg}$ (from Bi-214)
- K-40 < 1.7 mBq/kg
- Cs-137 < 44 mBq/kg

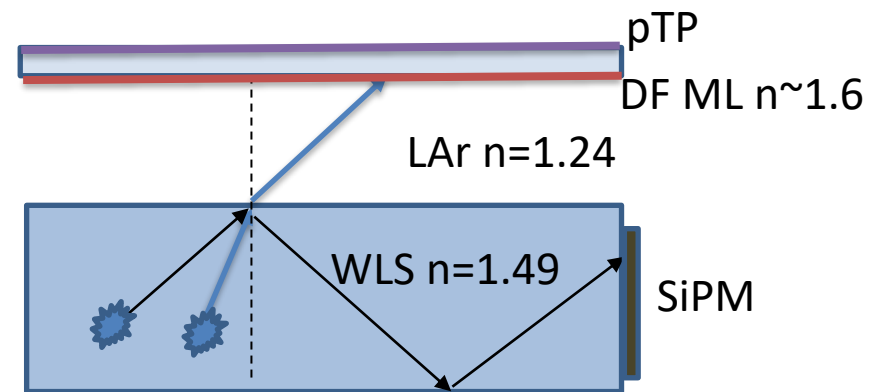
To be compared with Ar-39 (1 Bq/kg) and FR4 (O(10mBq/kg))

This material can be employed for low background applications

- SoLAr, Legend,...

WLS: Attenuation length (λ_{att})

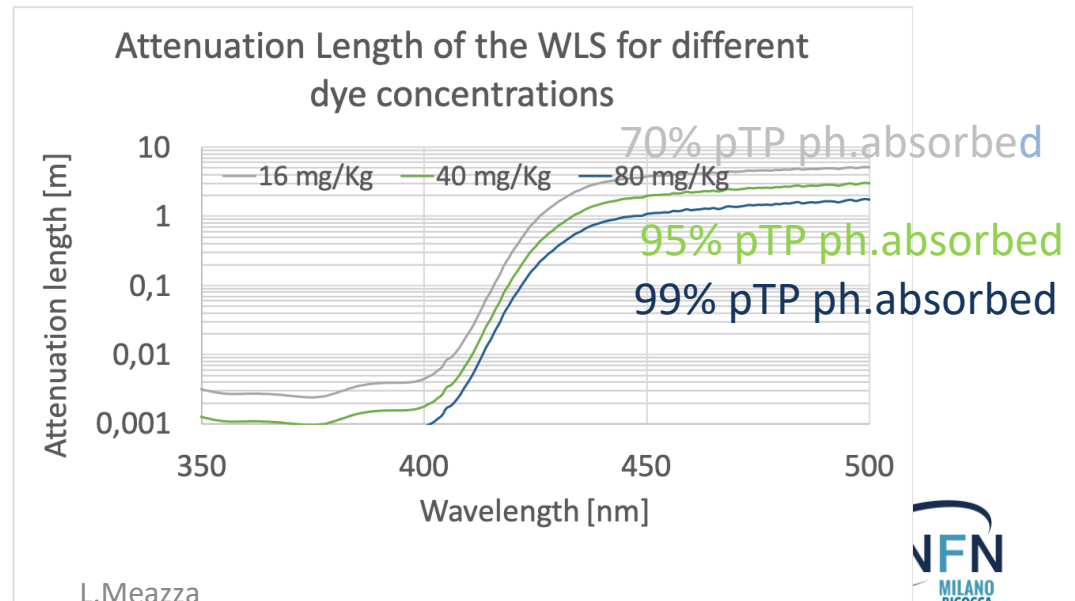
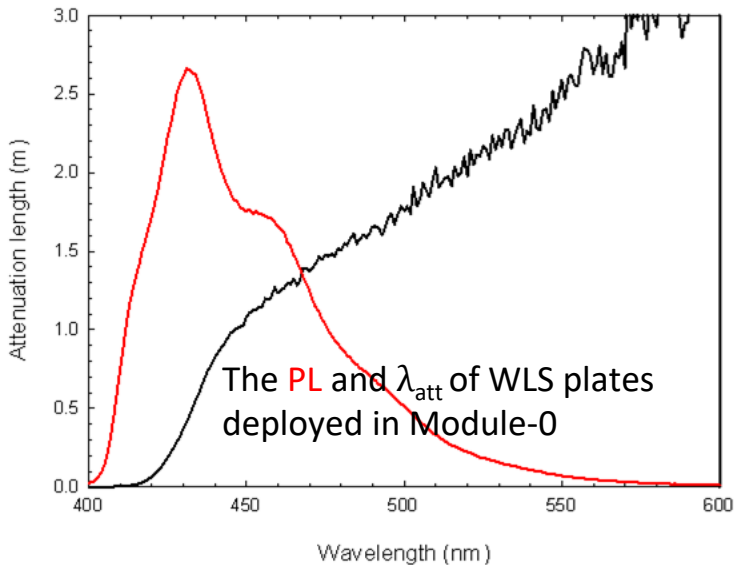
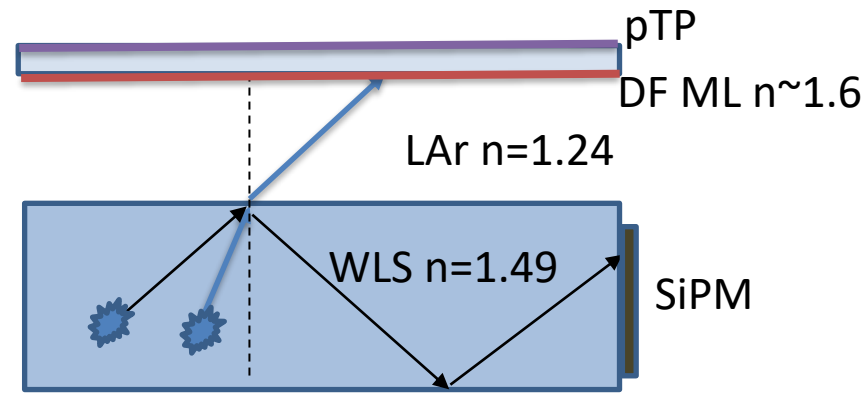
- For PMMA based WLS in LAr, the critical angle for light trapping at the surfaces is $56^\circ = \theta_c$. For $\theta > \theta_c$ light is trapped and guided by TIR to SiPMs.
- Due to multiple reflections the optical path inside large size WLS (as for FD2 of DUNE) may reach a couple of meters.
- The WLS attenuation length λ_{att} is the leading parameter for high efficiency large area WLS-lightguides



WLS: Attenuation length (λ_{att})

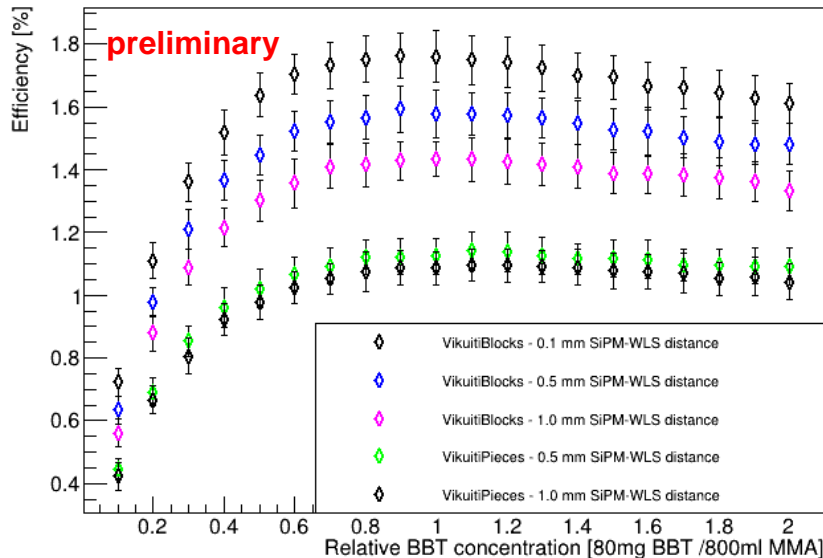
The dye concentration of the DUNE - FD1: must be

- tailored for the FD2 WLS size and optical path.
- Optimization (driven by sims)

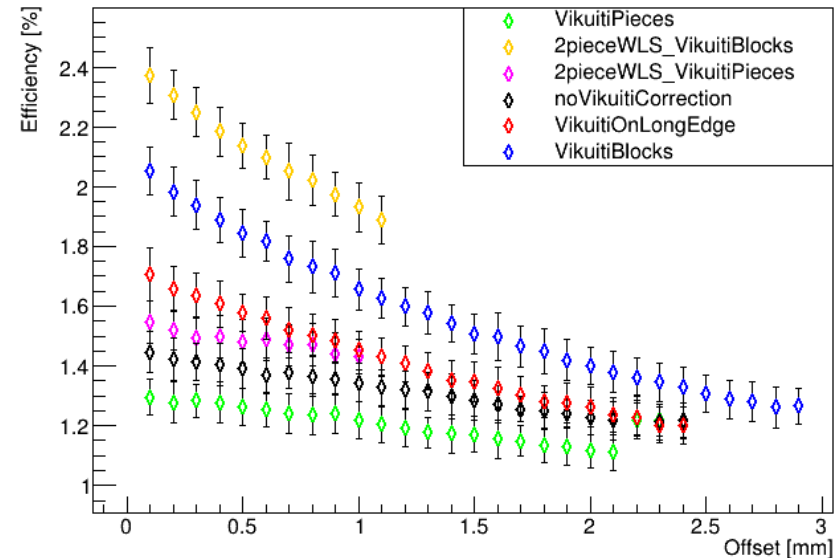


- an optical simulation can be employed to evaluate the impact of different variables on the light collection efficiency:
 - chromophore concentration
 - distance from the lightguide edge
 - ...

BBT concentration scan

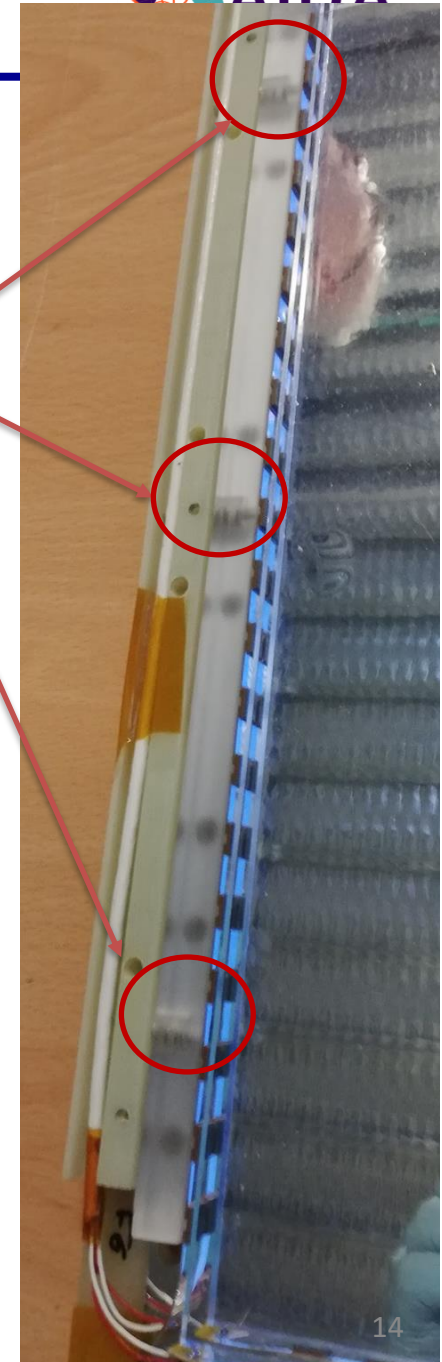
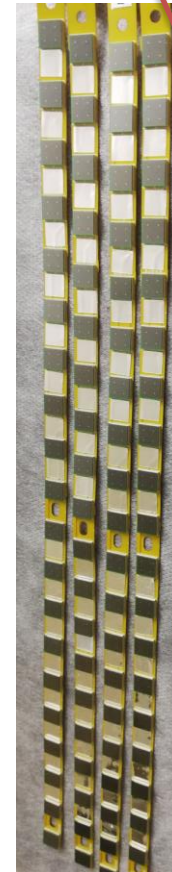
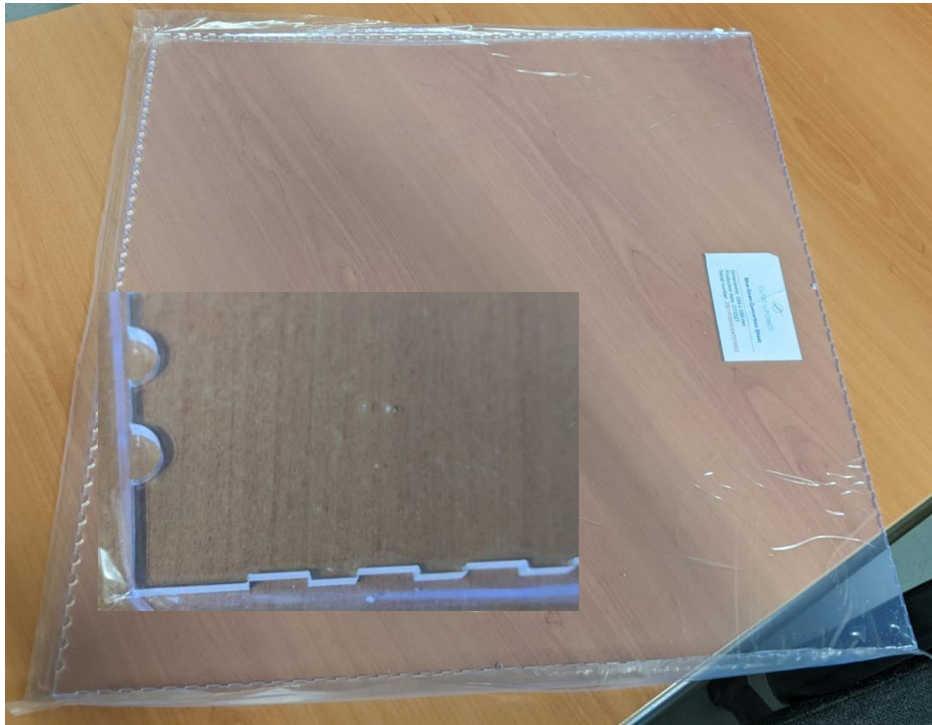


SiPM Offset Scan



SiPM to WLS coupling

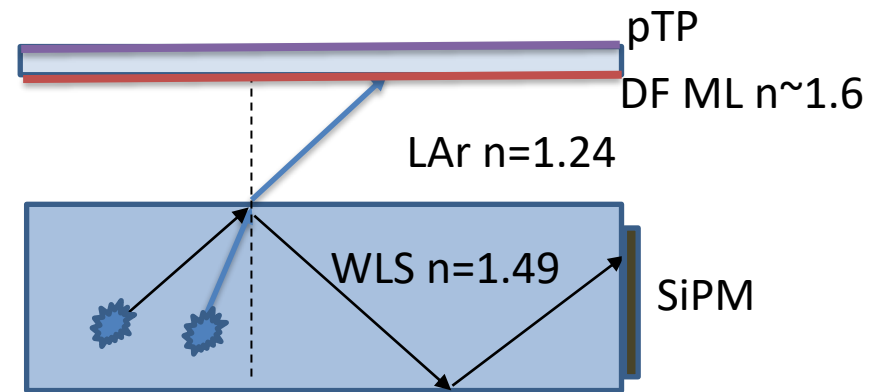
- BL design: WLS with flat edges
- Also tested SiPMs fitting in dimple-cuts (flat/cylindrical) machined at the edges of the WLS
- In LAr SiPMs are kept in close contact to WLS thanks to flex circuits & spring loaded mechanism, to compensate the WLS shrinking ($\sim 1\%$. i.e. 6 mm)



- Dichroic Filter (DF) are made of thin film multilayer coatings on a glass/fused silica substrate. They act as Fabry-Perot interferometer to selectively transmit/reflect light.
- For Large volume LAr detectors => Large area DF
- The glass window is coated with a primary WLS (pTP) to downshift the 128 nm light to ~350 nm

DF specifications

- $\Lambda_{cutoff} = 400 \text{ nm}$ at AOI = 45° in LAr (61° in air 41° in H_2O)
- $T > 90\%$ $320 \text{ nm} < \lambda < 380 \text{ nm}$ (pTP emission)
- $T < 5\%$ $420 \text{ nm} < \lambda < 500 \text{ nm}$ (WLS emission)
- Stability of the DF multilayer at cryogenic T (no flaking or cracking)
- Coating uniformity over the large surface



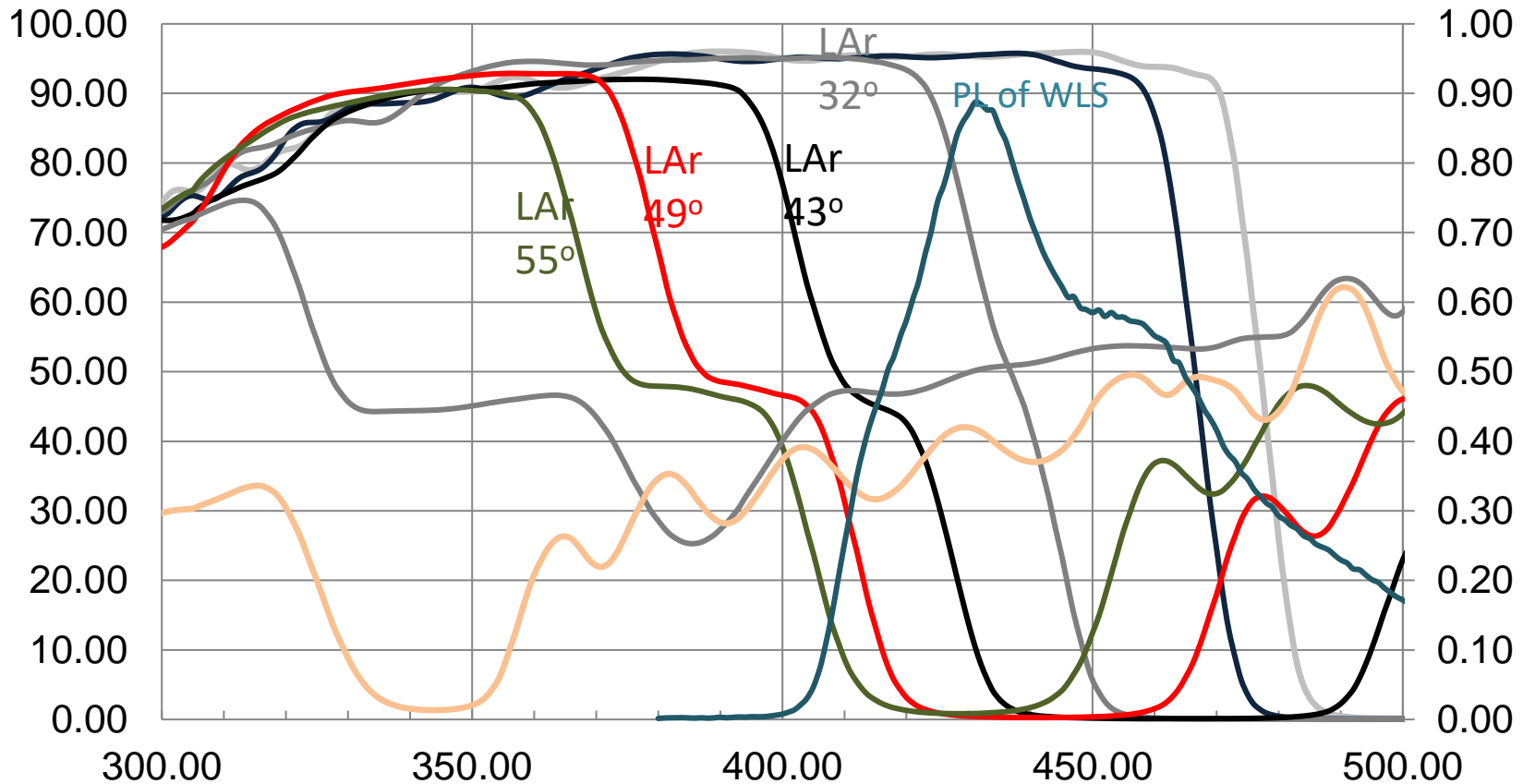
ZAOT (our industrial partner)
substrate

- Borofloat 33 Optical Glass
- OPTO (BL component) Substrate
- B270

ZAOT - T curves

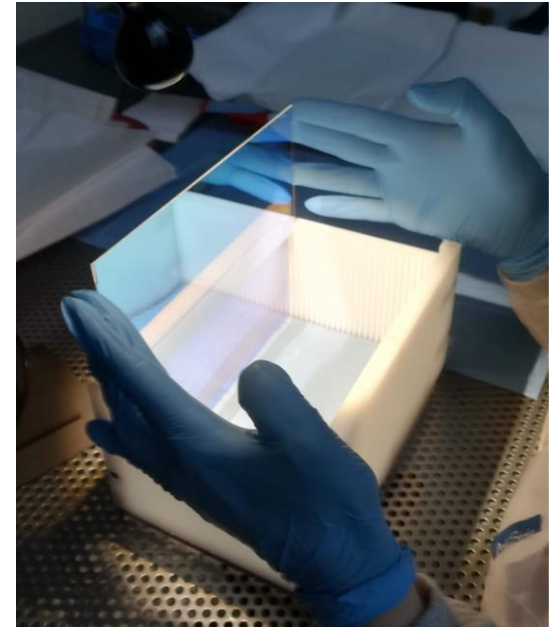
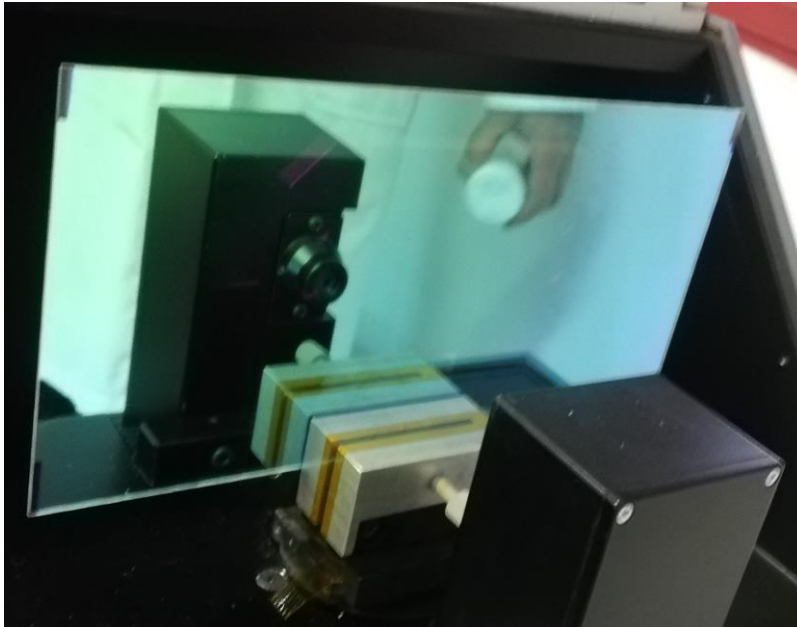
Cutoff change vs n =>
$$\lambda = \lambda_0 \sqrt{1 - \frac{n_1^2}{n_2^2} \sin^2 \theta}$$

ZAOT: Production of 18-Nov-22

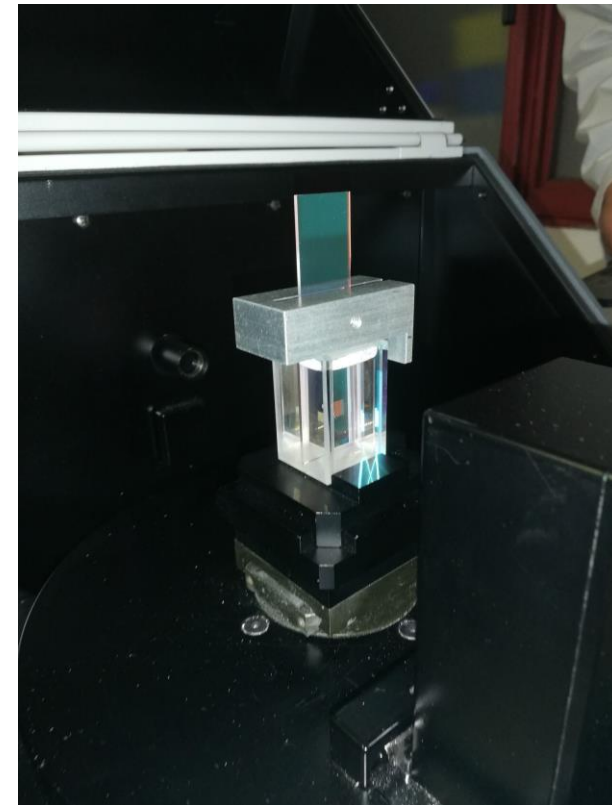
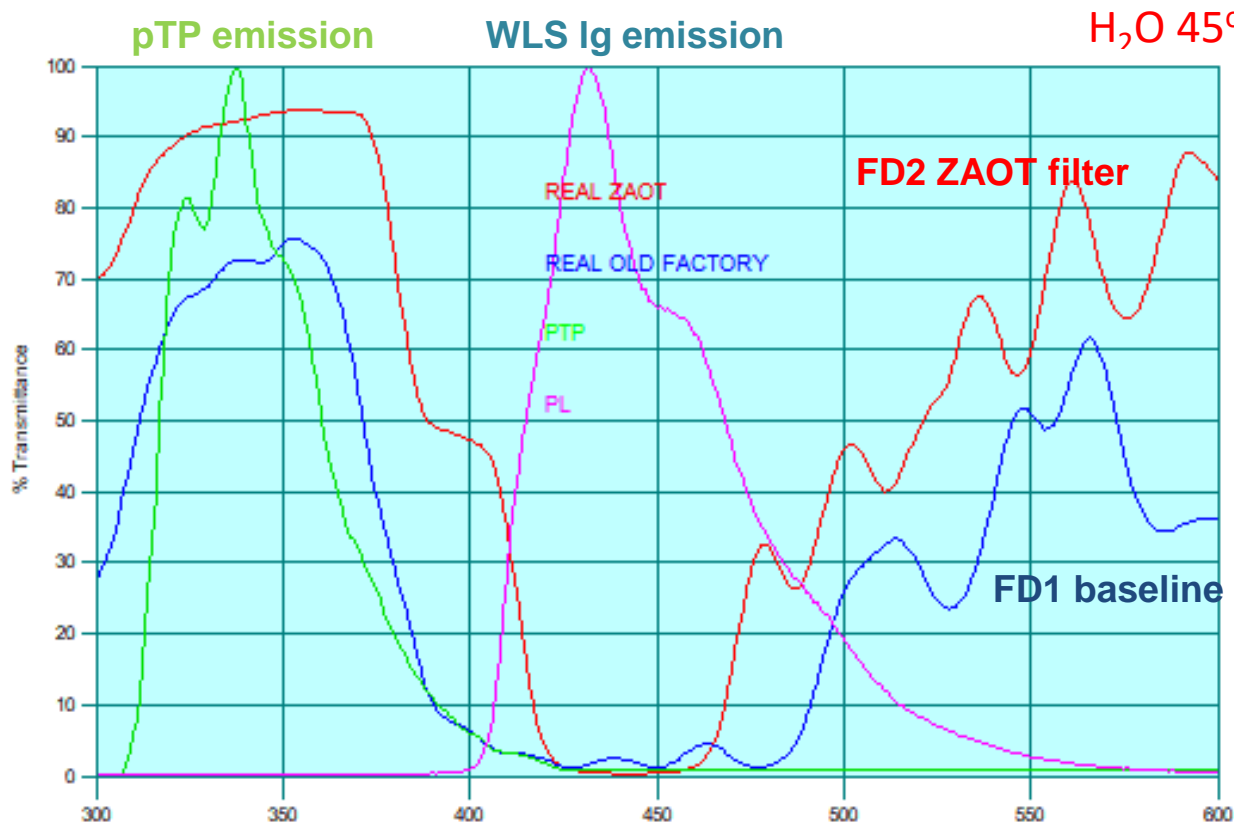


AOI in H₂O — 0° — 15° — 30° — 40° — 45° — 50° — 60° — 75° — PL

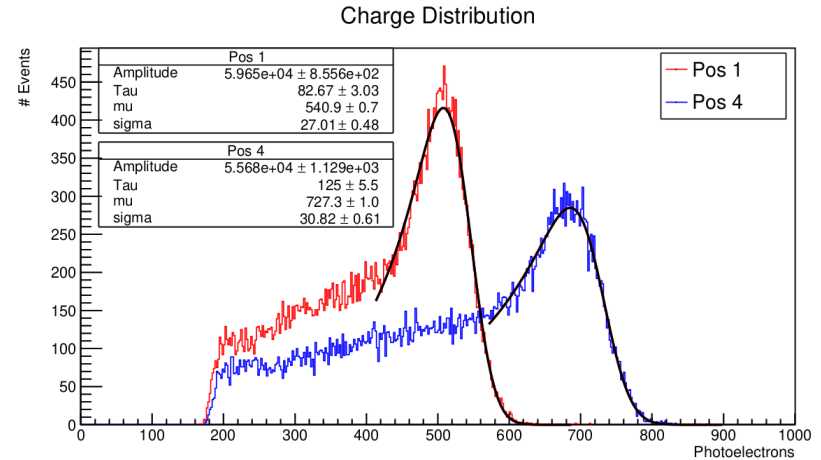
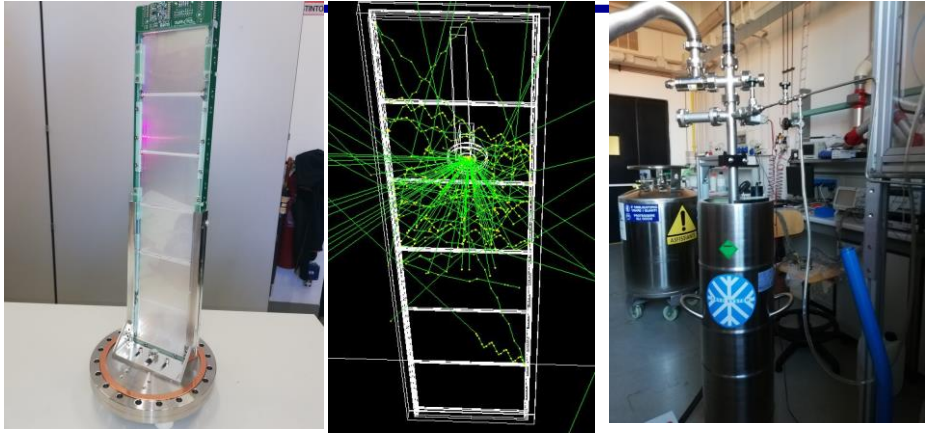
- ZAOT produced large area (150 x 150 mm²):
 - 265 DF for the Module-0 of the DUNE-FD2 for 10 XA Megacells (4 membrane + 6 cathode)
 - 54 DF for PDE Production capabilities of both vendors: > **120 DF in 5 w.d.**



- Filters have been optimized to operate in lAr (@45°)
 - Higher transmittance in the pTP emission range
 - Higher reflectivity in the light guide WLS chromofore emission range
 - But narrower reflectivity window



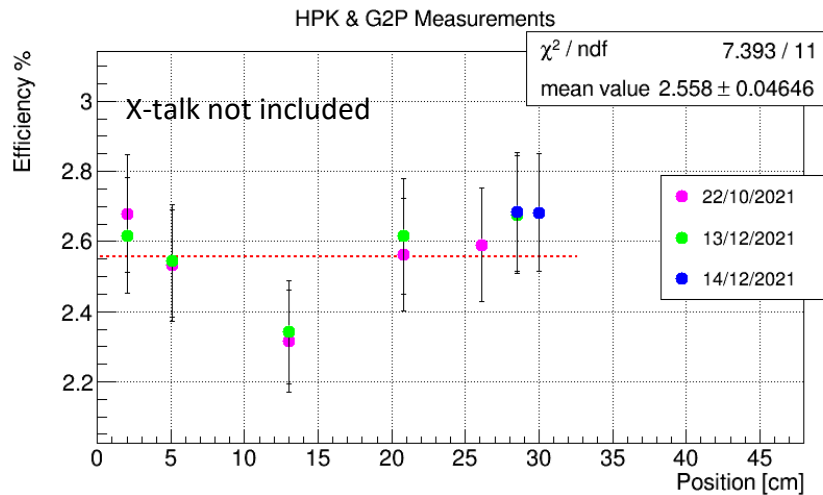
XA-PDE measurement method



Method: z-scanning of the whole cell (~2 Sr) with an ^{241}Am exposed α source

(JINST 16 (2021)09027)

$$\epsilon = \frac{4\pi \cdot \alpha \text{ peak(ADC)}}{\text{s.p.h.e.(ADC)} \cdot f_{int} \cdot LY_{\text{LAr}} \cdot \text{En}_{\alpha} \cdot q_{\alpha} \cdot \Omega}$$



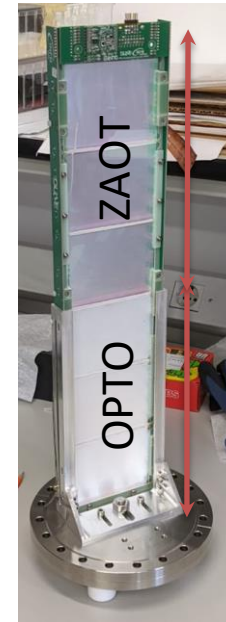
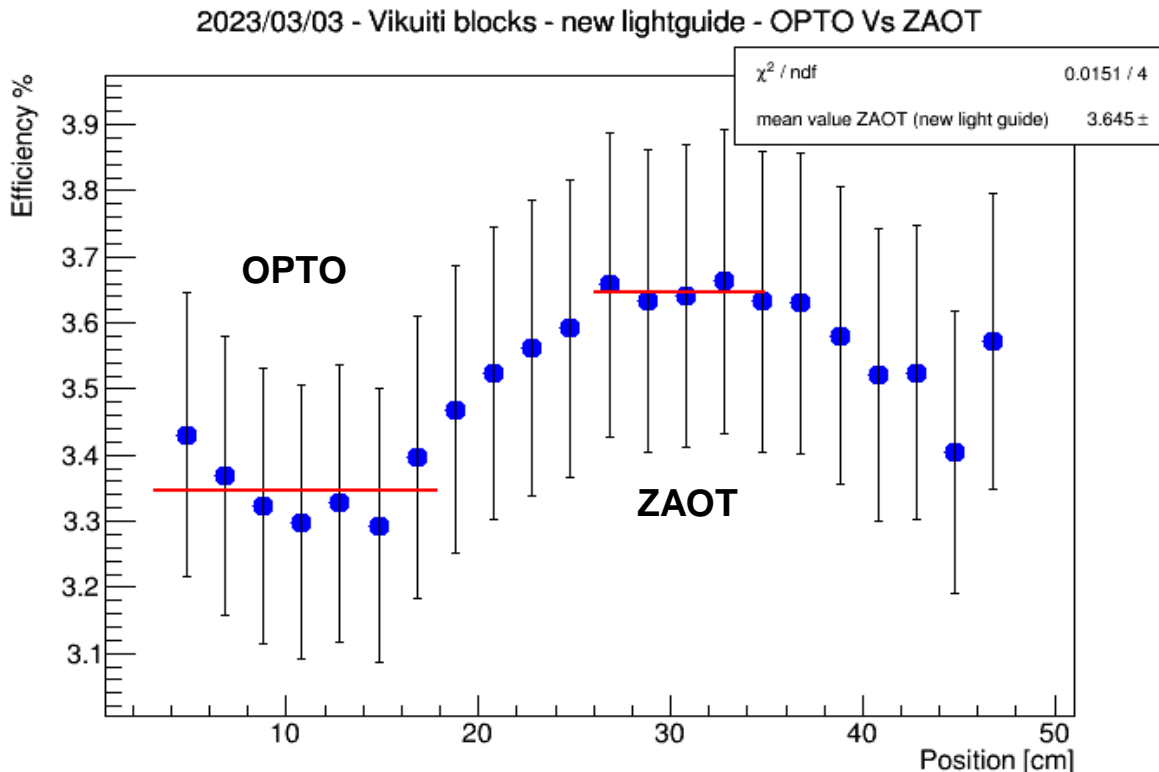
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No correction for LAr purity applied.
Expected: +2% to +5%

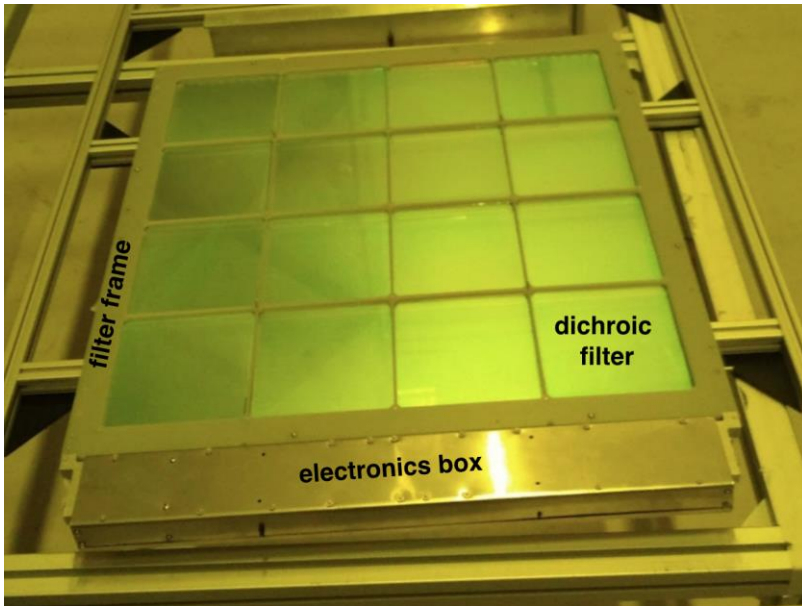
L.Meazza

	SiPM PDE	XA PDE MiB Xtalk corr.	XA PDE CIEMAT Xtalk corr.
HPK & G2P	50%	2.2 (0.15)	2.51 (0.21)
FBK & G2P	50%	1.9 (0.14)	
FBK & Eljen	50%	1.7 (0.14)	1.56 (0.12)

- Measurements of the PDE in LAr of one FD1-XA equipped with
 - three OPTO (0 < position < 24 cm)
 - three ZAOT (24 < position < 48 cm)
- Effect foreseen by GEANT based Simulations



Large area XA configurations



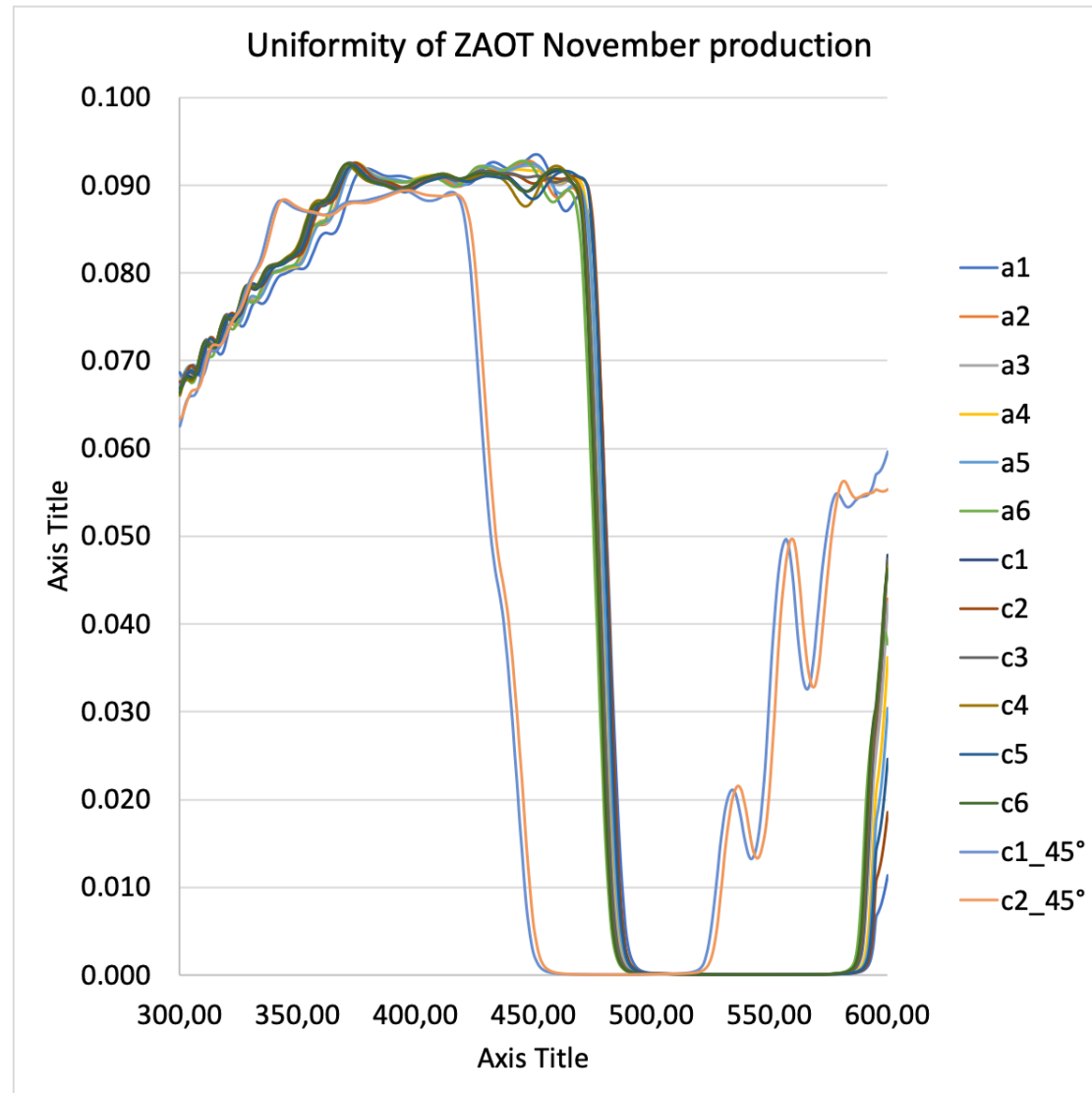
	WLS dimples	DF size (mm ²)	DF	SiPM	PoF	SoF	shared elec. box
M1		100x200	ZAOT	HPK			x
M2		100x200	ZAOT	HPK			x
M3	x	100x200	ZAOT	HPK			x
M4	x	100x200	ZAOT	HPK			x
M5	x	150x150	PE	FBK		x	
M6	x	150x150	PE	HPK			
M7	x	150x150	PE	HPK			
M8	x	150x150	PE	FBK			
C1		100x200	ZAOT	HPK	x	x	
C2		100x200	ZAOT	HPK	x	x	
C3		150x150	PE	FBK	x	x	
C4	x	150x150	PE	HPK	x	x	
C5	x	150x150	ZAOT	HPK	x	x	
C6	x	150x150	ZAOT	HPK	x	x	
C7	x	150x150	ZAOT	FBK	x	x	
C8	x	150x150	ZAOT	HPK	x	x	

- PDE measurements of the large area XArapuca will be performed at different sites:
 - INFN Naples
 - CIEMAT (Madrid)

Thank you!

DF coating uniformity

- two extreme positions (a and c) of the ML coating disk tested
- each of the two DF tested at 6 different points



The coating report from UniCAMP

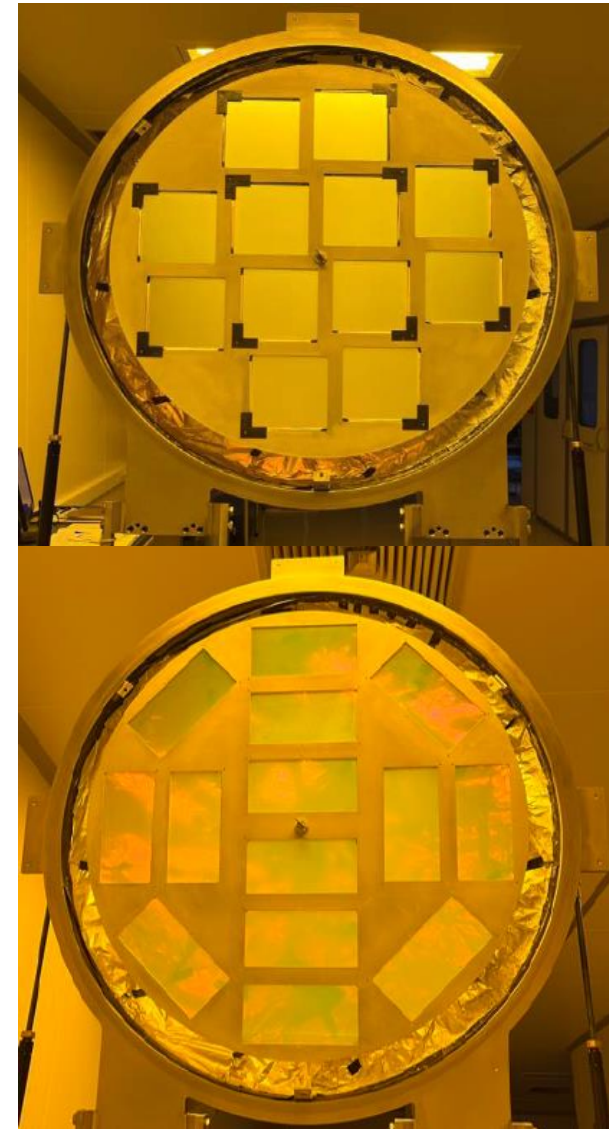
Date	Size	Disc position	Mass before	Mass after
26/01/23	143.75x143.75	Central (01)	66,62698 g	66,72385 g
26/01/23	143.75x143.75	External (07)	66,17028 g	66,22962 g
N. filters = 12		pTP = 4,000 g		Pc=2,2*10 ⁻⁵ mbar

Main pTP coating site: UNICAMP

Coating capabilities: 2 batches/day => 24/day

- Evaporation of ~400 ug/cm²
- Thickness: 3.2 um

Twin facility will participate at the FD2 pTP coating efforts at INFN Napoli starting from spring 2024



WLS Lightguides

